Diamond Detector – Amplifier notes

GEB 21-04-09

Charge Collector Distance δ and Efficiency ε

$\varepsilon = Q_{measured} / Q_{induced}$

$\delta = \varepsilon.d$ where d is detector thickness

δ [µm] = $Q_{measured} / 36$ where 36 electron-hole pairs per µm are created for a minimum ionizing particle (MIP) in Diamond and 13eV are required to generate an e-h pair.

For a single crystal diamond (sCVD), ε is claimed to be 100%, therefore $\delta = d$, although only thicknesses up to 500µm have been seen in papers. DDL claim ε = 100% for d = 1mm.

δ vs Field Strength E

For poly-crystalline Diamond (pCVD), δ saturates at values of E above 1V/µm. Some papers claim sCVD saturates around 0.25V/µm.

Electron-Hole Mobility µ and Pulse-width τ

$v_e = \mu.E$ where v_e is drift velocity [m/s], µ is electron mobility [m^2/Vs], E is electric field [V/m].

For pCVD v_e = 180µm/ns and v_h = 120µm/ns at E = 1V/ µm and μ_e = 1800 cm^2/Vs.

For high-purity sCVD v_e = 450µm/ns and v_h = 380µm/ns at μ_e = 4500 cm^2/Vs.

Pulse-width is approximately the mean of the electron-hole velocities and δ.

$\tau = 2\,\delta / (v_e + v_h)$ where v_e and v_h are electron/hole drift velocities respectively.

τ = 1.27ns for δ = 190µm in pCVD

τ = 2.41ns for δ = 1mm in sCVD

Initial Detector Current i_0

$i_0 = q.(v / d)$ and $q = q_M . d$ where q = total charge and q_M = charge per micron (36 e-h pairs in diamond).

$i_0 = q_M (v_e + v_h)$

For pCVD $i_0 = 36 \times (180 + 120) \times 10^9 \times 1.6 \times 10^{-19}$ = 1.73µA

For sCVD $i_0 = 36 \times (450 + 380) \times 10^9 \times 1.6 \times 10^{-19} = 4.78\mu A$

Amplifier Noise

Assume 60dB of gain required, split over three separate stages.

From Freescale MMG3001NT1 datasheet (Farnell 1578032)

BW ≥ 2GHz

Gain = 20dB nominal

Noise Figure (NF) = 4.2dB

F(noise factor) = 2.63

G(gain factor) = 10

From Friis: $F_{total} = F_1 + (F_2 - 1) / G_1 + (F_3 - 1) / G_1G_2$

$F_{total} = 2.63 + 1.63/10 + 1.63/100 = 2.81$

NF = 4.49dB

Amplifier Input

Assuming 50Ω input of amplifier then for sCVD

$V_{in} = i_0 . R = 4.78\mu A \times 50\Omega = 239\mu V$

Equivalent Noise Power $N_i = (F_{total} - 1).n_0.BW.3.\Pi/16$

Where $n_0 = 4 \times 10^{-21}$ W/Hz thermal noise.

$N_i = (2.81 - 1) \times 4 \times 10^{-21} \times 2 \times 10^9 \times 0.589 = 8.53pW$

As a RMS noise current $i_{Ni} = \sqrt{(N_i / R_{in})} = \sqrt{(8.53pW / 50)}$

$i_{Ni} = 0.41\mu A$

SNR is ratio of peak current i_0 to rms noise current i_{Ni}

SNR = 4.78/0.41 = 11.6 or 10.6dB.

Choice of Amplifier Components

For a pulse-width of 2.4ns, select a 2GHz bandwidth, low-noise amplifier. A gain of 60dB should give peak signals up to around 240mV. Use a 10-bit, 8GS/s digitizer to capture these signals.

Testing using ^{90}Sr Source

^{90}Sr decays via β^- with an energy around 0.54MeV. The source in the lab has an activity of ‘N’kBq and a solid angle of ‘M’ steradians. The equates to a Y particles on the diamond detector at a distance of X mm.

$Y = \text{area} / (M \times X^2)$.

The continuous detector current [A] = particle rate [/s] x energy [eV] x e-charge [C]/ 13 [eV]

For ^{90}Sr with 1000 particles/s at 0.54MeV this equates to a detector current of

$i = 1000 \times 0.54 \times 10^6 \times 1.6 \times 10^{-19} /13 = 6.6\text{pA}$

^{241}Am decays via α with energy 5.638MeV, which should increase the current by a factor of 10, but only if the source is very close (< few mm) from the detector. (E loss for α per mm in air?).